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STRUCTURAL PARTICULARS OF PORCELAIN ARTICLES MANUFACTURED BY SLIP CASTING

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The structural particulars of porcelain articles manufactured by the drain and solid methods of slip casting are determined. It is shown that the method used to manufacture an article can be identified. The data obtained can be useful for determining the mechanism of defect formation in porcelain manufactured by the casting method.

Key words: microstructure of porcelain, slip casting methods.

Different methods of forming an intermediate product — pressing, plastic formation, slip casting — are used to manufacture porcelain, depending on the form of the article and the technological possibilities. Large articles with a complex shape are manufactured predominately by casting slips — water suspensions of the initial mixture of clayey and stony materials to which different amounts of liquefiers are added [1].

This method is based on removing a portion of the water from the slip using a porous mold; this is accompanied by the formation of a layer of paste on the surface of the mold (casting). Drain and solid methods of slip casting are distinguished. Each method of casting has its own specific conditions of forming a casting, which ultimately affects the structure of the articles.

The drain method is characterized by the fact that a porous mold is filled with slip which is poured off after the intermediate-article wall with the require thickness is accumulated on the inner surface of the mold. Thin-wall hollow articles, sculpture, and vases are made in this way. In the solid method of casting the wall of the intermediate product is formed between two walls of a porous mold, which makes it possible to obtain castings with large and variable thickness. This method is used to make dishes, herring plates, cheese plates, spoons, and components of articles (handles).

The slip for porcelain manufacture consists of a liquid (water) and solid (clayey materials, feldspar, and quartz) phases. Kaolinite and montmorillonite are represented by non-isometric finely dispersed particles, whose size does not exceed 1 μm. The grains of stony materials (quartz and feldspar) after preliminary comminution in ball mills to size less than 60 – 100 μm acquire a fragmental elongated shape.

Investigations performed on thin and polished transverse sections of a wall of porcelain articles by means optical microstructural analysis established the characteristic features of the structure formed when using different slip casting methods.

It was found that layers differing by mineral and dispersion composition form in samples of porcelain formed by the drain method of slip casting. The structure of an article can be divided conventionally into four zones, excluding the glaze layer. The first zone is formed directly on the surface of the gypsum mold; it is enriched with clayey components. At the same time it contains fewer stony particles, which are smaller. The second zone is the main part of the casting in which stony and clayey components are present. The third zone is a thin interlayer consisting of clayey components with rare inclusions of fine grains of feldspar and quartz. The fourth zone is actually the inner surface of the article, located farthest from the surface of the gypsum mold and it is enriched with quartz and feldspar as compared with the neighboring layer.

A general feature of the structure is the distinct orientation of the grains of clayey materials which have an elongated plate shape. Such a separation was observed in all experimental porcelain articles and intermediate-articles, fabricated by the drain method, irrespective of the fabrication

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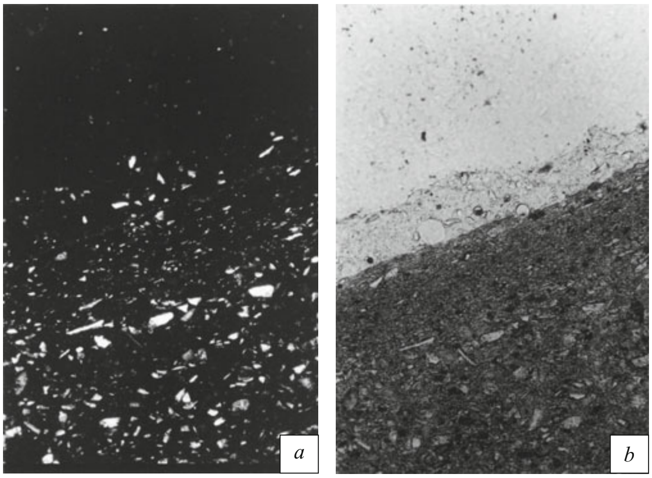

Fig. 1. Photomicrograph of the outer side of a porcelain article made from MR paste, fabricated by the casting method (× 141): *a*) polarized light (white grains — undissolved quartz grains); *b*) transmitted light.

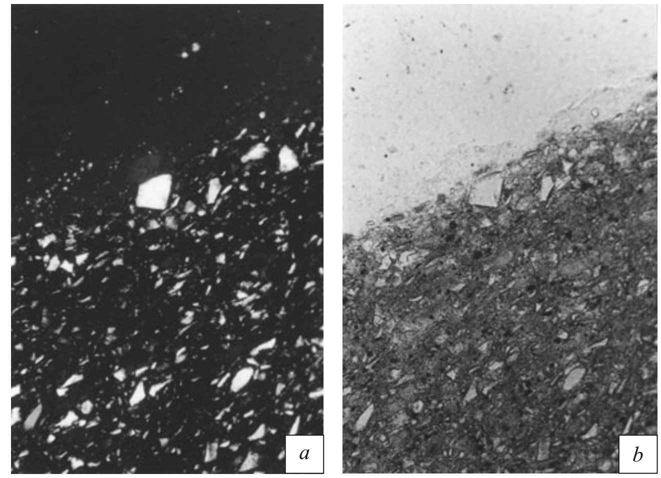

Fig. 2. Photomicrograph of the inner side of a porcelain article made from MR paste, fabricated by the casting method (× 141): *a*) polarized light (white grains — undissolved quartz grains); *b*) transmitted light.

time and location. It is most strongly expressed on the vertical walls of the article and thin-wall samples and less strongly on the bottom of the casting.

This phenomenon can be explained by the filtration process. Slow, smooth settling and the elongated or flat shape of the particles promote the formation of such a microlayered texture in sedimentary rocks [2]. In the drain method of slip casting the intermediate product is formed under the conditions of relatively slow filtration, which the penetrating porosity of the gypsum mold gives. In the first place, finely dispersed particles of clays settle on the surface of the mold, after which the main layer is formed with the solid particles keeping their orientation. After the required thickness of the article is reached and the excess slip removed, the filtration process in the casting continues. Fine particles of clayey materials move into the inner layer, uncovering the larger grains of quartz and feldspar. As a result a microlayer structure forms on the inner side of the article, farthest away from the surface of the gypsum mold. This can become the reason for the formation of cracks in the article and deformation. Table 1 gives the structural characteristics of 2 – 2.5 mm thick porcelain article, fabricated by the drain method from MR paste, into which quartz was introduced in the form of quartz sand, and fired at 1320°C. A section of the outer and inner sides this article is shown in the photographs (Figs. 1 and 2) in transmitted and polarized light, where sections with microlayer structure are seen according to the presence and arrangement of the grains of undissolved quartz as well as the formation of zones with low porosity. In Fig. 3 one can see under an approximately 100 μm thick surface layer of glaze a change in the character of the porosity of the porcelain on the outer and inner sides of the article (polished section, reflected light).

TABLE 1. Structural Characteristics of 2 – 2.5 mm Thick Porcelain Article Fabricated by the Drain Method

Arrangement of the zone studied	Zone width, μm	Porcelain structure						Structure of glaze layer		General description of the structure
		Undissolved quartz grains			Pores			Thickness, μm	Size of the contact layer, μm	
		Volume fraction, %	Size, μm average	Size, μm maximum	Volume fraction, %	Size, μm average	Size, μm maximum			
Outer surface of the article	100 – 180	6.2	12.1	60	5.9	9.1	45	100	10 – 15	Oriented, micro-layered near the inner surface
Middle of the wall of the article		13.0	16.7	100 – 110	7.1	11.0	60 – 80	–	–	
Near the inner surface	20 – 50	7.4	10.7	40	About 4	–	To 20	–	–	
Inner surface of the article	100 – 120	12.8	17.3	100	9.7	11.5	60 – 70	100	5 – 10	

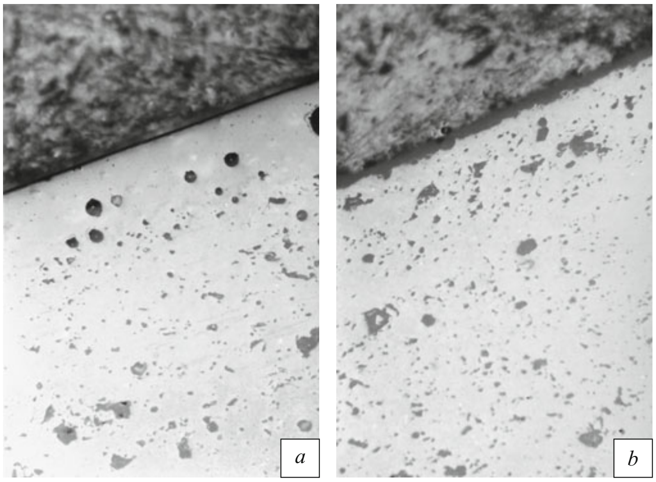

Fig. 3. Photomicrograph of a porcelain article made from MR paste, fabricated by the drain method, reflected light, black areas) pores (× 141).

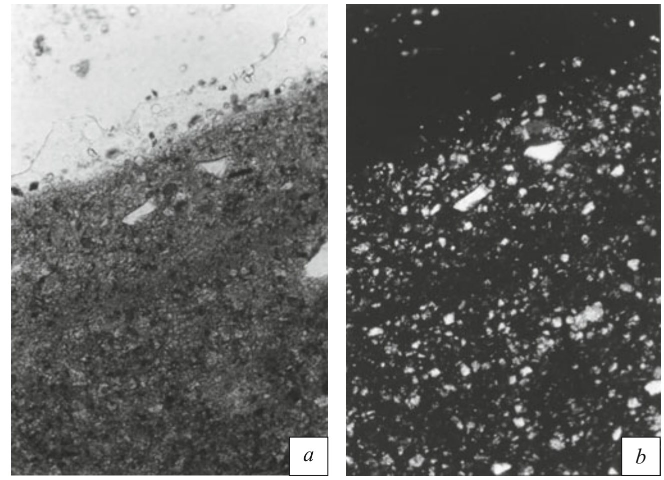

Fig. 4. Photomicrograph of the inner side of a porcelain article fabricated from MG paste by the drain method (× 141): *a*) polarized light; *b*) transmitted light.

It turned out that the processes indicated proceed not only in pastes in which the quartz grains are represented by fragmental elongated grains, which can serve as a reason for the formation of oriented structures [3]. Figure 4 gives images of a section of the inner surface of an article fabricated from MG paste based on Gusev porcelain stone with quite isometrically shape grains of quartz calcined at 1320°C, where separation of layers is also observed. The thickness of the separation zone with respect to the total thickness of the article wall is small (fractions of a percent). Figure 5 shows the values of these ratios for 10 arbitrarily chosen samples of porcelain fabricated from MR paste with different wall thickness, which were fabricated by the casting method (Y1 — layer on the inner surface of an article, enriched with quartz grains; Y2 — neighboring layer with low quartz content). The separation is sharpest in thick-wall samples. The differences of the structural parameters of a porcelain article on the outer and inner sides affect the formation of the glaze layer on its surface. No significant difference in the thickness of the glaze layer was found, but in the contact layer at the boundary of the glaze — porcelain on the outer surface, which at the intermediate-product stage is enriched with clayey components, needles of mullite are formed more intensely and they are large in size as compared with the contact layer on the inner side.

Separation was also found in samples of porcelain fabricated by the solid method. The first zone is formed on the surface of the gypsum mold and its indicators are similar to those of drain casting, its magnitude is 200 – 250 μm. The second zone is the main layer of the article. The zones are located symmetrically on both sides from the central zone of thickness to 200 μm, which can be observed on a section or shear surface of the article in the form of a thin, darker band located along the center of the article. The central zone con-

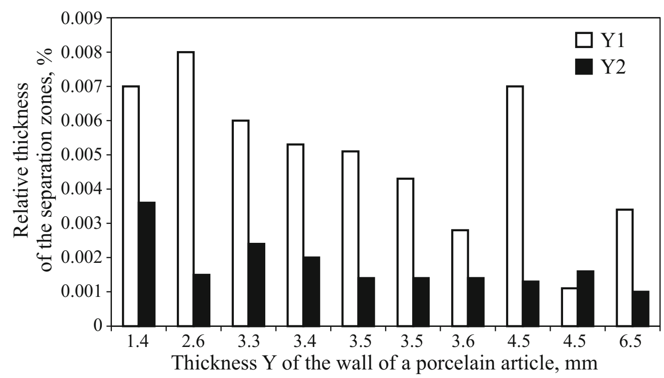

Fig. 5. Relative thickness of the zones of separation (Y1, Y2), %, with respect to the thickness of the wall of the porcelain article: zone Y1) layer on the inner surface of the article, enriched with quartz grains; zone Y2) neighboring layer with low quartz content.

tains a larger number of quite large grains of quartz and feldspar.

At the initial stage of solid casting, processes similar to those described above occur. Next the layer of paste grows on both sides of the mold. Then both sides of the casting join, and particles of the solid phase undergo redistribution at the joints due to the continuing filtration process. The clayey components partially migrate into the casting, leaving in the central zone larger grains of stoney materials. Thin interlayers (from 10 to 40 μm thick) consisting predominately of clayey particles and a small number of grains of quartz and feldspar in both sides of the central zone were observed on some samples. Along the entire thickness of the casting the elongated particles of the stoney materials were oriented parallel to the surface of the mold. Table 2 gives the structural characteristics of a porcelain article fabricated from MR paste with thickness 7 mm by the filling method, and cal-

TABLE 2. Structural Characteristics of 7 mm Thick Porcelain Article Fabricated by the Bulked Method

Arrangement of the zone studied	Zone width, μm	Porcelain structure						Structure of glaze layer		General description of the structure
		Undissolved quartz grains			Pores			Thickness, μm	Size of the contact layer, μm	
		Volume fraction, %	Size, μm: average	Size, μm: maximum	Volume fraction, %	Size, μm: average	Size, μm: maximum			
Outer surface of the article	180 – 200	9.7	12.3	60	7.8	8.5	25 – 30	120	5 – 15	Oriented, with pronounced central zone
Depth from 300 μm to 3 mm below outer surface	–	14.5	16.7	110	8.8	10.6	80	–	–	
Central zone (joint)	170 – 200	17.8	20.8	110	18.3	23.5	80	–	–	

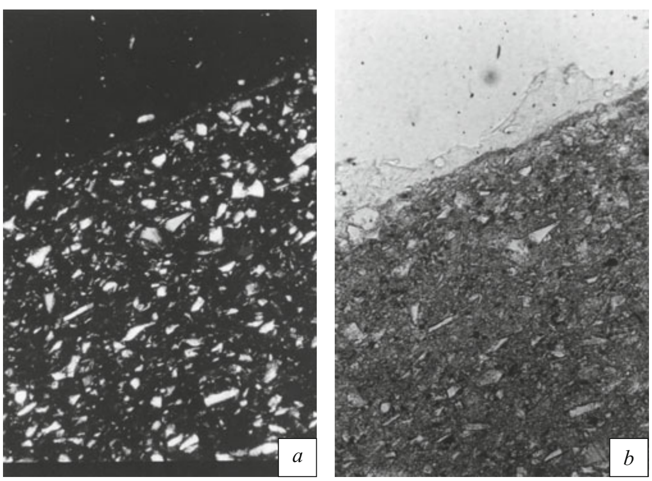

Fig. 6. Photomicrograph of the outer side of a porcelain article fabricated from MR paste by the solid method (× 141): *a*) polarized light (white grains) undissolved quartz grain); *b*) transmitted light.

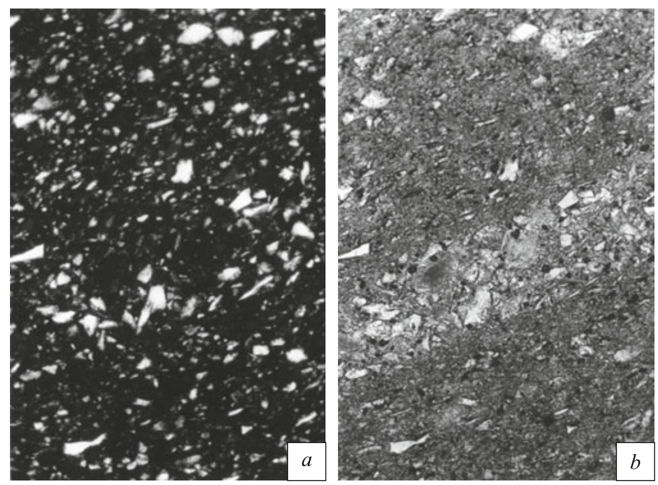

Fig. 7. Photomicrograph of the central zone of a porcelain article fabricated from MR paste by the solid method (× 141): *a*) polarized light (white grains) undissolved quartz grain); *b*) transmitted light.

cined at 1320°C. The central zone (seam) differs by an elevated content of large grains of undissolved quartz and pores. Images of a section of the outer side and central zone of an article fabricated from MR paste are presented in Figs. 6 and 7. This type of structure was found in all articles fabricated by the sold method irrespective of the composition of the paste and production location.

In conclusion, it can be stated that porcelain fabricated by the casting method from water suspensions possesses a characteristic structure which is inherent only to each concrete method. This phenomenon can be used tp develop materials with a prescribed structure and when it is necessary to identify the method used to fabricate the article. The data obtained could be helpful to determine the mechanism by which defects appear in porcelain fabricated by the casting method.

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